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SUBJECT Notes on Indium, Germanium, and Titanium

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(a) A List of Indium Chemicals - dated 15 Jan 45

(b) Extraction of Indium - dated 18 Jan 45

(c) Purification of Indium - dated 18 Jan 45

(d) Sources of Indium - dated 18 Jan 45

(e) A List of Uses and Prospective Uses of Indium - undated

(f) Sources of Germanium - dated 26 Jan 45

(g) Uses and Alleged Possible Uses of Germanium - undated

(h) Notes on Titanium - undated

(i) Memorandum (Revised July 2, 1947) Metals, minerals, gases, and other substances which may have increased commercial interest owing to their association with the development of atomic energy./

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10

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Next 3 Page(s) In Document Exempt

MEMORANDUM 1/18/45

Indium
Extraction of Indium

Indium is usually extracted from indium-bearing ores, concentrates, minerals, metals, alloys, metallurgical residues, flue dust, calcines, fumes, distillation plant dust and other by-products by one of the following methods:

Method I. Zinc blends are dissolved in HNO_3, and the heavy metals are precipitated by H_2S. From the filtrate indium is precipitated with excess ammonia and this precipitation is repeated several times to remove zinc and manganese. The final $In(OH)_3$ is dissolved in acetic acid and then precipitated as sulfide by H_2S as In_2S_3. To remove any remaining small amounts of iron, the In_2S_3 is dissolved in HCl, a little HNO_3 being added to oxidize the iron. Then the addition of NH_3 precipitates $Fe(OH)_3$ with only a little indium. After removing all the iron, pure $In(OH)_3$ is precipitated by adding an excess of ammonia.

Method II. Indium-bearing zinc metal is treated with dilute H_2SO_4 just insufficient to effect complete solution. A spongy mass of lead, copper, cadmium, tin, arsenic, iron and indium collects upon the residue of undissolved zinc. This spongy material is collected, washed, dissolved in HNO_3, and evaporated with H_2SO_4. The $PbSO_4$ is filtered off, and the hydroxides of iron and indium are precipitated with NH_4OH. This precipitate is dissolved in a small amount of HCl, and the solution is brought close to the neutral point, then boiled with an excess of $NaHSO_3$. By this treatment a basic sulfite is obtained which has the formula $In_2(SO_3).In_2(OH)_6.5H_2O$. This is dissolved in H_2SO_4, and finally $In(OH)_3$ is precipitated by an excess of NH_4OH.

Method III. A complex indium-bearing ore may be ground and then subjected to flotation by which concentrates of zinc and indium, lead, and silver are obtained. The zinc-indium concentrate may be treated as follows:

(A) Roasted with salt (NaCl). The indium chloride is dissolved and metallic indium is deposited electrolytically.

(B) Dissolve in H_2SO_4, and precipitate the indium (a) by the addition of zinc, or (b) by neutralization of the excess acid.

The purity of the metal is increased by repeating the process. A purity of 99% and higher is claimed.

MEMORANDUM

1/18/45

Indium
Purification of Indium

The most persistent impurity encountered in the isolation of indium is iron. The following methods have been suggested to effect the desired purification.

Method I. Precipitate $In(OH)_3$ from mixed solutions by adding $BaCO_3$.

Method II. Add NaCl, evaporate to dryness, take up the residue with cold water, and treat with H_2S. Repeat the process several times.

Method III. Add KCNS to mixed chlorides in acid solution, and extract $Fe(CNS)_3$ with ether.

Method IV. Add alcoholic pyridine solution to mixed chlorides, and precipitate colorless $InCl_3 \cdot 3C_5H_5N$. Both $FeCl_3$ and $AlCl_3$ remain in solution.

Method V. Sublime $InBr_3$ in a stream of CO_2, leaving $FeBr_2$ as a residue.

MEMORANDUM

1/19/45

Indium
Sources of Indium

Most of the available and reasonably recoverable indium is closely associated with zinc or zinc-bearing ores and minerals, and most of this indium is contained in the mineral sphalerite, either incorporated physically or in solid solution.

Hence it is obvious that most of the commercial indium is recovered as a by-product in some form of zinc metallurgy. It is safe to say, up to now, that no indium is recovered commercially as a result of the treatment of any indium-bearing material as a result of the treatment of such material for its indium content alone.

From an academic standpoint it is of interest to tabulate the various minerals known to contain indium, ranging from sphalerite, which contains relatively "substantial" quantities, down to those minerals wherein the metal occurs in minute or even infinitesimal percentages.

These minerals are:

1. Sphalerite, zinc sulfide, ZnS. In this mineral, the indium content usually ranges from 0.01% to 0.1%; rarely, if ever, in excess of 0.2%. As a matter of fact, the usual indium content of most sphalerite is, in all probability, less than 0.01%, or say less than 2 oz. per ton. Many samples of sphalerite give no indication of containing any indium as a result of ordinary chemical tests. For example, it is reported that the examination of 68 samples of zinc blendes from various localities revealed the presence of indium in 37. On the other hand, it has been estimated that mid-western zinc concentrates may run as high as 15 oz. per ton.

2. A complex ore containing the sulfides of lead, zinc, iron, copper, silver and gold, owned by the Indium Corporation of America, near Kingman, Mohave County, Arizona, is reported to average 1.93 oz. of indium per ton. It is claimed that 50,000 tons of this ore has been developed, equivalent to 96,500 troy ounces of indium, or approximately one year's potential production of by-product indium at Anaconda.

3. Zinc-bearing minerals other than Sphalerite. The zinc content of these minerals is variable. It is probable that the indium content is roughly proportional to the zinc. The more abundant of these minerals, and hence those that are likely to contribute most of the available indium are indicated by an asterisk(*) in the following alphabetical lists. The others, not so indicated, either contain minor percentages of zinc or they are relatively scarce or of local interest. It is almost certain that they are of little importance as sources of indium, but they are presented for the sake of completeness or for their academic interest.

Adamite, $Zn_3As_2O_8.Zn(OH)_2$ or $4ZnO.As_2O_5.H_2O$
Alphahopeite, $3ZnO.P_2O_5.4H_2O$ (index of ref. 1.591)
*Alunite, $KAl_3(OH)_6(SO_4)_2$
Arakawaite, $4CuO.2ZnO.P_2O_5.6H_2O$
*Aurichalcite, $2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$
Austinite, $CaZn(OH)AsO_4$
Berylliumvesuvianite, $2(Mg,Mn,Zn)O.6CaO.4BeO.Al_2O_3.6SiO_3$
Betahopeite, $3ZnO.P_2O_5.4H_2O$ (index of ref. 1.582)
Brackebuschite, $(Pb,Fe,Mn,Zn)_3.V_2O_8.H_2O$
Brickerite, $4ZnO.3CaO.2As_2O_5$
*Calamine (hemimorphite), $H_2Zn_2SiO_5$ or $(Zn\ OH)_2.SiO_3$ or $Zn_4SiO_7(OH)_2.H_2O$
Chalcophanite, $(Mn,Zn)O.2MnO_2.2H_2O$
Chlorophoenicite, $10(Mn,Zn)O.As_2O_5.7H_2O$
Clinohedrite, $ZnO.CaO.SiO_2.H_2O$
Danalite, $3(Fe,Zn,Mn)O.3BeO.3SiO_2(Fe,Zn)S$ or $(Be,Fe,Zn,Mn)_7Si_3O_{12}S$ or $(Fe,Zn,Mn)_2(Zn,Fe)_2S)Be_3(SiO_4)_3$
Descloizite, $(Pb,Zn)(Pt,Zn)(OH)_2$ or $4(Pb,Zn)O.V_2O_5.H_2O$
Dysluite, $(Zn,Fe,Mn)O.(Al,Fe)_2O_3$
*Franklinite, $(Fe,Zn,Mn)(Fe,Mn)_2O_4$
Gageite, $8(Mg,Mn,Zn)O.3SiO_2.2H_2O$
Gahnite, $ZnAl_2O_4$ or $ZnO.Al_2O_3$
Glaucokerinite, $10(Zn,Cu)O.2Al_2O_3.SO_3.7H_2O$
Goslarite, $ZnSO_4.7H_2O$ or $ZnO.SO_3.7H_2O$
Guadalcazarite, $(Hg,Zn)S$
Gumucionite, (arsenic-bearing sphalerite)
Hardystonite, $Ca_2ZnSi_2O_7$ or $2CaO.ZnO.2SiO_2$
Helvite, $(Mn,Fe)_2(Mn_2S)Be_3(SiO_4)_3$
Hemimorphite (V. Calamine)
Hetaerolite, $2ZnO.2Mn_2O_3.H_2O$ (index of ref. 2.344)
Hodgkinsonite, $2ZnO.MnO.2SiO_2.H_2O$
Holdenite, $8MnO.4ZnO.As_2O_5.5H_2O$
Hopeite, $Zn_3(PO_4)_2.H_2O$
Hydrohetaerolite, $2ZnO.2Mn_2O_3.H_2O$ (V. hetaerolite)
Hydrozincite, $2ZnCO_3.3Zn(OH)_2$ or $ZnCO_3.2Zn(OH)$ or $3ZnO.CO_2.2H_2O$
Jeffersonite, $(Mn,Zn,Fe,Mg)O.CaO.2SiO_2$
Koettigite, $ZnO.As_2O_5.8H_2O$ or $Zn_3As_2O_8.8H_2O$
Kreittonnite, $(Zn,Fe,Mg)O.(Al,Fe)_2O_3$
Larsenite, $PbZnSiO_4$ or $PbO.ZnO.SiO_2$
Legrandite, $28\ ZnO.9As_2O_5.25H_2O$
Leucophoenicite, $\&(Mn,Zn,Ca)O.3SiO_2.H_2O$
Loseyite, $7(Mn,Zn,Mg)O.2CO_2.5H_2O$
Manganotantalite, $MnO(Ta,Cb)_2O_5$
McGovernite, $21(Mn,Mg,Zn)O.3SiO_2.\frac{1}{2}As_2O_3.As_2O_5$
Mooreite, $8(Mg,Mn,Zn)O.SO_3.11H_2O$
Nicholsonite (a zinc-bearing aragonite with zinc up to 10%, found in Leadvil
Colorado; theoretical formula possibly: $5ZnCO_3.21CaCO_3$)
Paraurichalcite (a zinc-malachite)(?)
Phosphophyllite, $3(Zn,Fe,Mn)O.P_2O_5.4H_2O$
Psittacinite, $(Pb,Cu,Zn)_3.V_2O_8.(Pb,Cu,Zn)(OH)_2.H_2O$ or $4(Pb,Cu,Zn)O.V_2O_5.H$

[illegible]
[illegible], ZnCO$_3$
[illegible], [illegible]ZnO.P$_2$O$_5$.4H$_2$O
Spinel, (Fe,Mg,Mn,Zn)O.(Al,Fe,Mn)$_2$O$_3$
Sussexite, H(Mn,Mg,Zn)BO$_3$
Tarbuttite, [illegible].P$_2$O$_5$.Zn(OH)$_2$
Tennantite, (Cu,Fe,Zn,Ag)$_{12}$.As$_4$S$_{13}$ or generally [illegible] or 4Cu$_2$S.Sb$_2$S$_3$
Troostite, (Zn,Mn)$_2$SiO$_4$ (another name for Willemite, Zn$_2$SiO$_4$ or 2ZnO.SiO$_2$)
Vesselyite, 7(Cu,Zn).8(OH).(P,As)$_2$O$_5$.9H$_2$O or 7([illegible])(P,As)$_2$O$_5$.9H$_2$O
Voltzite, 4ZnS.ZnO or Zn$_5$S$_4$O
Willemite, Zn$_2$SiO$_4$ or 2ZnO.SiO$_2$
Wolftonite (a magnetic oxide of manganese and zinc, containing about 47% Mn and 19% Zn, and a trace of Fe; theoretical formula possibly: 16 MnO$_2$.15ZnO.xFe)
Wurtzite, ZnS
Yeatmanite, (Mn,Zn)$_{16}$Sb$_2$Si$_4$O$_{29}$
Zincaluminite, 2ZnSO$_4$.4Zn(OH)$_2$.6Al(OH)$_3$.5H$_2$O or 6ZnO.3Al$_2$O$_3$.2SO$_3$.18H$_2$O
Zinc-Copper Melanterite, CuO.ZnO.2SO$_3$.14H$_2$O
Zincite, ZnO
Zincschefferite, (Mg,Mn,Zn)O.CaO.2SiO$_2$
Zinkosite, ZnSO$_4$.7H$_2$O

4. Minerals which do not contain Zinc but which frequently contain Indium:

*Astrophyllite, (Na,K)$_4$(Fe,Mn)$_4$Ti(SO$_4$)$_4$
*Cassiterite, SnO$_2$
*Copper Ores (such as tennantite and tetrahedrite)
*Huebnerite, MnWO$_4$
*Iron Ores (such as pyrite and pyrrhotite)
*Lead Ores (such as galena, cerussite and anglesite)
*Manganotantalite, MnO(Ta,Cb)$_2$O$_5$
*Pegmatites (usually consist of microcline or orthoclase, quartz and muscovite)
*Phlogopite, KMg$_2$Al$_2$Si$_3$O$_{10}$(OH)$_2$ or 2K$_2$O.10(Mg,Fe)O.3Al$_2$O$_3$.12SiO$_2$.3H$_2$O or (H,K(Mg,F))$_3$.Mg$_3$Al(SiO$_4$)$_3$ or H$_2$KMg$_3$Al(SiO$_4$)$_3$ + K(Mg,F)Mg$_3$Al(SiO$_4$)$_3$
*Pyrite, FeS$_2$
*Pyrrhotite, Fe$_{1-x}$S or Fe$_x$S$_y$ or Fe$_{11}$S$_{12}$, actually varies from Fe$_5$S$_6$ to Fe$_{16}$[illegible]
*Rhodonite, MnSiO$_3$
*Samarskite, (Fe,Ca,UO$_2$)$_3$(Cer,Yttr,ThO$_2$,ZrO$_2$)$_3$(Nb,Ta)$_6$O$_{21}$. This mineral is essentially a columbate (niobate) and tantalate of iron and calcium with the cerium(Cer) and yttrium(Yttr) metals, together with uranium oxide. The yttrium oxides vary from 6 to 15%, and the cerium oxides from 2 to 6%. Tantalum pentoxide, Ta$_2$O$_5$, and columbium pentoxide, Cb$_2$O$_5$(same as neobium pentoxide, Nb$_2$O$_5$) make up about 50%. The formula is sometimes written 3(Fe,Ca,UO$_2$)O.(Ce,Y)$_2$O$_3$(Cb,Ta)$_2$O$_5$ or (Fe,Ca,UO$_2$)$_3$(Ce,Y)$_2$(Nb,Ta)$_6$O$_2$
*Siderite, FeCO$_3$
*Wolframite, (Fe,Mn)WO$_4$
*Zircon, ZrSiO$_4$

5. Metals, Alloys and Metal Salts which frequently contain Indium, or with which it is closely associated:

- Cadmium, Cd
Cobalt, Co
Gallium, Ga

Iron Sulfide, FeS, FeS_2 and Fe_2S_3
Lead Sulfide, PbS
Thallium, Tl
Zinc sulfide, ZnS

6. Residues and By-Products at smelters and other Metallurgical and Chemical manufacturing plants, such as:

Bag-house fume
Blue powder from distillation of zinc ores
Brass furnace flue dust
Cadmium-bearing flue dust
Cadmium sponge (0.14 to 0.2 oz. per ton)
Calcines
Chloride fume (0.25 to 0.3 oz. per ton)
Chloridized calcines (0.3 to 0.5 oz. per ton)
Cobalt cake (4 to 5 oz. per ton)
Condensed flue dust and fume from brass-melting furnaces.
Copper blast-furnace fume
Copper cake (0.02 to 0.05 oz. per ton)
Cottrell plant fume
Distillation plant dust and fume
Electrolytic plant dust and fume
Filtration plant sludges and residues
Flue dust (from roasting and remelting furnaces, and sintering machines)
Fumes (from roasting furnaces and sintering machines)
Furnace fumes
Lead blast-furnace fume
Lithopone plant by-products and residues
Metallurgical residues
Refinery residues (electrolytic zinc)
Residues from electrolytic lead refineries
Roasting-furnace fume
Shriver cake (0.04 to 0.05 oz. per ton)
Sintering machine dust and fume
Smelter by-products
Vat residues from electrolytic zinc plants
Vat residues from zinc liquors in the manufacture of lithopone
Zinc dust formed in the distillation of zinc ores
Zinc residues (0.25 to 0.5 oz. per ton)

A List of Uses and Prospective Uses of Indium

Age-hardening of aluminum alloys
Age-hardening of copper alloys
Aircraft instrument protection against damage by salt water spray
Airplane engine bearings
Airplane propellers
Alloy age-hardening
Alloying ingredient for silver
Alloys
Aluminum alloy age-hardening
Amalgams (dental)
Automobile hardware
Babbits
Ball bearings
Band instruments
Barber chair and equipment trim
Bearings
Bearing surfaces
Brass band instruments
Brazing alloys
Bus engines
Cadmium conservation
Cadmium-indium alloys
Cadmium-silver bearings (plating of)
Cartridge cases
Castings (dental)
Cast silver
Ceramics
Checking oxidation
Chemicals (best known are: trichloride, $In\,Cl_3$; sulphate, $In_2\,(SO_4)_3\cdot$[illegible]); and
sesquioxide, In_2O_3
Clips
Close-tolerance plating
Coating for silver
Colorant in glass (yellow)
Combat aircraft engine bearings
Compounds
Compressive strength in dental alloys
Conservation of other metals
Contact points (electrical)
Control rods (Ordnance)
Copper alloy age-hardening
Copper-indium alloys
Copper-lead bearings
Corrosion resistant
Cylinder wall protection
Dairy equipment coatings
Decorative finishes

Dental alloys
Dental chair and equipment trim
Dental instrument plating
Diesel engines
Diesel marine engines
Die-stuff mordant
Diffused plating
Diffusion coatings
Electrical contacts
Engine bearings
Experimental work at Watervliet Arsenal
Fatigue prevention
Finishes (decorative)
Finishing metal surfaces
Flash coatings on cadmium, silverware, and dental equipment.
Floodlights (reflecting surfaces)
Flow-under-pressure resistance
Fusibility increaser
Fusible alloys
Glass colorant (yellow, any shade from light canary to tangerine)
Glass manufacture
Gun carriages (plating)
Gun leveling plates
Hardening metals (age-hardening of Cu and Al)
Hardness increaser in metals
Hardware (exterior trim)
Hardware for automobiles
Headlights (plating)
Headlights (reflectors)
High-duty internal combustion engines
High-polish surfaces
High-temperature thermometers
Impregnation of metal surfaces
Indium-cyanide-dextrose plating bath.
Indium plating
Indium-treated lead (stronger and harder)
Hinges in spectacle frames
Instruments (musical)
Instrument protection
Jewelry (Plating and alloys)
Leveling plates for guns
Light reflectors
Low-melting alloys
Lubrication (Machine-gun parts)
Machine gun parts
Machine tools (plating)
Matte finished deposits
Melting range increase in alloys
Mercury alloys (amalgams)
Metal age-hardening
Metal finishing

Military uses
Mirrors (front-surfaced)
Mordant for die stuffs
Motor car trim
Musical instruments
Nickel-indium alloys
Non-corrosive coatings
Non-ferrous metal plating
Optical glass
Optical goods (plating)
Ordnance
Oxidation resistant
Pharmaceuticals
Pin hole smearing
Piston protection
Plating parts for machine guns
Plungers (ordnance)
Polished fixtures
Propellers (airplanes)
Protection of metals against organic acids in lubricants
Protection of metals against salt-water spray
Pratt & Whitney engines
Reflectors (plating)
Research
Resistance to tarnish
Rifle Clips
Rolls-Royce aircraft engine bearings
Salt spray protection
Searchlights (reflectors)
Setting-change resistance
Shoulder bushings (ordnance)
Silver alloy ingredient
Silver-indium bearings
Silverware
Small arms bearings
Small pins (in hinges of spectacles)
Smearing to close pin holes
Solders (increases fusibility and wetting qualities)
Soluble anodes
Spectacle frame hinges
Stability increase of metals
Steel-backed bearings
Steel blade propellers
Steel protection (after a flash coating of another metal)
Steel rods (plating)
Strength increase of dental alloys (compressive)
Surface diffusion
Surface hardness
Surgical instruments plating
Synthetic anti-malarials

MEMORANDUM January 26, 194

Germanium
Sources of Germanium

Germanium is widely distributed in nature, but it occurs usually in minerals which are very rare or in more abundant minerals in minute quantities. It is usually found as a sulfide or associated with sulfide ores. The minerals wherein it is found may be divided into two classes, namely those known to contain germanium as a component, and having been so identified mineralogically, and those wherein it is held mechanically, or possibly in solid solution.

1. Minerals wherein germanium occurs as a constituent are listed as follows:

Argyrodite, Ag_6GeS_5 or $3Ag_2S.GeS_2$, or $4Ag_2S.GeS_2$, containing from [illegible] to 7% germanium. Winkler first isolated the metal from this mineral, the supply coming from Freiberg, Germany. It is found also in the silver mines of Ormo, Bolivia.

Canfieldite, $4Ag_2S.(Sn,Ge)S_2$, containing from 1.82% to 6.5% germanium. Also found in Bolivia.

Euxenite, a complex mineral containing Nb, Ti, Y, Er, Ce, U, and [illegible]. It is a recognized source of Ge, [illegible], Y, and Nb. Its probable formula is [illegible]$(Ti,Nb)_2.Fe(\ldots)_6$

Germanite, [illegible] or [illegible]$(Cu,Fe)S.As_2S_3.2GeS_2$. This mineral is found at Tsumeb, South West Africa. Its germanium content varies from [illegible] to as much as 8.7%. Following are analyses of two different lots of a saleable ore of this type:

Lot I	
Cu	44.01%
S	30.96
Fe	5.08
As	6.83
Zn	2.74
Pb	2.26
Ga	0.57
Ge	5.00
W	0.03
SiO_2	1.84
$BaSO_4$	0.02
17 other elements	0.66
Total	100.00%

Lot II	
Cu	38.60%
S	26.90
Fe	4.20
As	7.36
Zn	4.00
Pb	7.90
Ga	0.14
Ge	3.08
Mo	0.28
Balance	7.94
	100.00%

Ultrabasite, $28PbS.11Ag_2S.3GeS_2.2Sb_2S_3$. This is a sulfide ore of lead, silver and antimony, containing about 2.2% germanium. It [illegible] found in Freiberg, Saxony.

2. **Sphalerites** constitute the most abundant source of germanium. It appears that the low-temperature deposits contain a higher percentage of germanium than the high-temperature deposits. Sphalerite from Joplin, Mo. and Picher, Okla. carry as much as 0.1% to 1.0% gallium, and the metal is found in the zinc blendes of Butte, Mont. Wisconsin ores are reported to carry 0.01% gallium. Certain British blendes are said to contain 2% to 4%.

Urbain made a spectroscopic examination of 64 specimens of zinc blendes from widely scattered areas and found germanium in 38 of them. Similarly, the spectroscopic examination of 68 Spanish zinc blendes revealed gallium in 50 specimens.

Its recovery as a by-product in zinc metallurgy is simple since the metal either burns to GeO_2 and collects in the baghouse dust or Cottrell dust; or the oxide is reduced by carbon at a red heat, and since the metal is only slightly volatile at 1350° C., it collects in the spelter retort residues.

3. Other minerals wherein Germanium has been found:

Bauxite, a mixture of aluminum of aluminum hydroxides, varying from $Al_2O_3.3H_2O$ to $Al_2O_3.2H_2O$ and $Al_2O_3.H_2O$, usually $Al_2O_3.2H_2O$

Cassiterite, SnO_2

Columbite, $(Fe,Mn)(Cb,Ta)_2O_6$

Copper (native copper), Cu

Enargite, $3Cu_2S.As_2S_5$ (usually from a trace to .01%; in Butte, Mont. sometimes as high as 0.1% GeO_2

Feldspars, silicates of Al with K, Na, and Ca, rarely Ba.

Franckeite, $Pb_5FeSn_3Sb_2S_{14}$ (a rare tin-lead sulfostibide)

Graphite, C

Lepidolite, $(K,Li)_2O.Al_2O_3.3SiO_2.F$ or $K_2Li_3Al_4Si_7O_{21}(OH,F)_3$

Leucite, $K_2O.Al_2O_3.4SiO_2$ or $KAlSi_2O_6$

Meteorites, (found in seven types)

Mica; especially lepidolite, but also in biotite, $(K,H)_2O.2(Mg,Fe)O.$ $(Al,Fe)_2O_3.3SiO_2$, and muscovite, $K_2O.3Al_2O_3.6SiO_2$

Pegmatite dykes (usually in the silicate constituents)

Samarskite,	$(Fe,Ca,UO_2)_3(Cer.Yttr,ThO_2.ZrO_2)_3(Nb,Ta)_6O_{21}$. This mineral is essentially a columbate (niobate) and tantalate of iron and calcium with the cerium (Cer) and yttrium (Yttr) metals, together with uranium oxide. The yttrium oxides vary from 6 to 15%, and the cerium oxides from 2 to 6%. Tantalum pentoxide, Ta_2O_5, and columbium pentoxide, Cb_2O_5(same as neobium pentoxide, Nb_2O_5)make up about 56%. The formula is sometimes written $3(Fe,Ca,UO_2)O.(Ce,Y)_2O_3(Cb,Ta)_2O_5$ or $(Fe,Ca,UO_2)_3(Ce,Y)_2(Nb,Ta)_6O_2$
Silicates,	from pegmatite dykes
Smithsonite,	$ZnCO_3$, near Salem, Ky., assays as high as 0.01% GeO_2
Spodumene,	$LiAlSi_2O_6$
Tantalite,	$(Fe,Mn)Ta_2O_6$
Tin Ores	(found in [illegible] out of 12)
Topaz,	$Al_2O_3(OH,F).SiO_2$. Germanium usually present. It was found in each of 34 specimens. A topaz from Silver Leaf Mine, Manitoba, assayed 0.1% GeO_2
Tourmaline,	a borosilicate of K,Li,Mg,Fe, and Al. Formula uncertain. It may be: $(Na,Ca)(Al,Fe,Li,Mg)_3B_3Al_3(AlSi_2O_9)_3.(O,OH,F)_4$

4. Other Materials and By-Products which are sources of Germanium.

Bag-house dust
Cadmium electrolyte
Coal (near Newcastle, England and in certain U. S. low-ash coals)
Cottrell dust
Dust (bag-house, Cottrell, and flue dust)
English coal, near Newcastle, carries as much as 1.6% GeO_2
Flue dust
Gas works dust (0.15% to 1.4% GeO_2)
Low-ash coals in U. S.
Mineral waters
Newcastle coal (England)
Residues recovered in the production of spelter.
Sea plants
Soils (sometimes 0.005% Ga. Said to stimulate plant growth)
Solar spectrum (scientific interest)
Spelter retort residues.
Zinc oxide from flue dust.

Syrup cups (plating)
Tarnish resistant
Temperature control apparatus
Thermometers (high-temperature)
Tin-indium alloys
Tinless solders
Tools (plating)
Trim (external hardware)
Trim for automobiles
Truck engines
Typewriter assemblies
Washers (plating)
Wearing quality of bearings improved
Wear-resistance coatings
White Metal bearings
Wire
Zinc-indium alloys
Zinc-indium coatings on propellers

Uses and Alleged Possible Uses of Germanium

Absorption spectra of glass more widely dispersed
Achromatic combinations produced with silica glass
Aircraft engine alloys (strength and light wt.)
Aluminum-germanium alloys
Alloys with mercury, aluminum, magnesium, silver and copper
Anemia remedy
Camera lenses
Carcinoma treatment proposed
Chemicals
Constituent of optical glass
Copper-Ge alloys
Corrosion-resistant alloys
Density of boro-crown glass increased
Dental inlays (Ge-Au alloys)
Devitrification of glass increased
Dispersion quality of glass increased
Displaces silver from its solutions
Durability of glass decreased
Expansion coefficient of glass increased slightly
Experimental work
Fatigue-reducing alloys
Germanium-aluminum alloys
Gold-Ge alloys
Hardness of magnesium and copper increased
Magnesium-Ge alloys
Mercury-Ge alloys
Optical glass refractive power increased
Pernicious anemia remedy
Pharmaceutical in treatment of pernicious anemia
Refractive index of flint glass increased
Research
Rolling qualities of aluminum said to be improved (?)
Silver-Ge alloys
Softening temperature of glass lowered
Strength of aluminum said to be increased (?)

NOTES ON TITANIUM

SUMMARY

(A brief topical condensation of over 1000 references and memoranda

I. HISTORY.
  1. Discovery by Rev. William Gregor in 1789, in Ilmenite.
  2. Found by Klaproth in 1795, in Rutile.
  3. Pure oxide prepared by Rose in 1821.
  4. Pure metal prepared by Hunter in 1910.

II. OCCURRENCE IN NATURE.
  1. Eighth most abundant metal, and ninth most abundant element, constituting 0.62% of the earth's crust.
  2. Geographical distribution.
  3. Rocks.
  4. Minerals.
  5. Ores.
  6. Associations.

III. OCCURRENCE AS A BY-PRODUCT in the treatment or recovery of other metals or mineral substances.

IV. PHYSICAL PROPERTIES.
  1. Atomic weight 47.90.
  2. Atomic number 22.
  3. Isotopes 46,47,48,49,etc.
  4. Melting point 1800°C.
  5. Boiling point above 3000°C.
  6. Density 4.5.
  7. Electrical resistivity [illegible] X 10^{-6} ohm-cm.
  8. Radius Ti^{+4} ion in crystals [illegible] cm. X 10^{8}.
  9. Ductility, hardness, luster, etc.

V. CHEMICAL PROPERTIES.
  1. Chemical reactions.
  2. Affinities.
  3. Heats of formation.
  4. Stability.
  5. Unique characteristics, etc.

VI. DETECTION.
  Twelve qualitative methods.

VII. ESTIMATION.
  1. Gravimetric methods.
  2. Volumetric methods.
  3. Colorimetric methods.
  4. Oxidimetric methods.
  5. Analysis of titanium materials.
  6. Preparation of reagents.

[illegible] theory.
[illegible] applications of chemical theory.

[illegible].
1. Present state of development.
2. [illegible] methods of preparing elemental titanium.
3. Forms of product.

X. COMPOUNDS.
1. Four basic classes and their variations.
2. Individual compounds and their characteristics.
3. Pertitanic compounds.

XI. USES.
1. Uses of elemental titanium.
2. Alloys.
3. Ferrotitanium: grades, uses and beneficial effects.
4. Applications and functions in steel.
5. Applications in cast iron.
6. Effects on magnetic properties, grain size, etc.
7. Incandescent media for lighting purposes.
8. Dyes, mordants, bleaching agents, strippers, etc.
9. Refractory materials and ceramics, glazes, enamels, glasses and bricks.
10. Salts as reducing agents.
11. Smoke screens and pyrotechnics.
12. Soaps.
13. Coagulants.
14. Pigments and their preparation and properties.
15. Effects of refractive indices.
16. Paper.
17. Rayon.
18. Rubber.
19. Linoleum.
20. Leather.
21. Plastics.
22. Abrasives.
23. Catalysts.
24. Printing ink.
25. Silk printing.
26. Welding rods.
27. Tooth paste.
28. Face powders.
29. Oils.
30. Medicinal preparations.
31. Nitrogen fixation.
32. Phosphorus pentoxide liberation.
33. Applications in pure science.
34. Numerous special applications.

XII. COSTS.

XIII. [illegible] [illegible] AND PATENTS.

[illegible]. ([illegible] 1500)

MEMORANDUM

(Revised July 2, 1947)

Metals, minerals, gases, and other substances which may have increased commercial interest owing to their association with the development of atomic energy.

Note: Not strictly confidential, but not for general circulation.

* These items are of special importance.

Actinium (radioactive)
*Aluminum (for cooling pipes)
Barium
Antimony
*Beryllium (for cooling pipes)
*Bismuth (molten, for cooling; solid, for cooling pipes)
Boron
Bromine
*Cadmium (absorber)
*Carbon (moderator)
Chemicals (in uranium chemistry)
Chlorine
*Concrete (shielding)
Corrosion-resistant alloys
Detector materials (rhodium, indium, iodine)
Deuterium (heavy hydrogen)
Dysprosium (absorber)
Europium (absorber)
Fluorine
*Fluorite
Gadolinium (absorber)
*Gallium (in alloys; and in atomic research)
Germanium (in alloys; and in atomic research)
*Graphite (moderator; and in "pile" construction)
*Heavy water (moderator)
Helium (for cooling)
Hydrogen
Indium (detector; and as foil)
Iodine (detector)
Lanthanum
*Lead (for cooling pipes; and for shielding)
Lithium
*Magnesium (for cooling pipes
Mercury
Metal foils
Moderators (carbon, graphite, heavy water)
*Monazite (source of thorium)
Nitrogen
Oxygen
Palladium
Paraffin
Polonium

Protoactinium (radioactive)
Radium (radioactive)
Radioactive minerals ~~(see special list)~~
Rhodium (detector)
Selenium
Samarium (absorber)
*Steel (shielding)
Tellurium
*Tin (for cooling pipes)
Thorium (radioactive)
Titanium (alloys; refractories; atomic research)
Tungsten
*Uraninite (important mineral source)
*Carnotite (important mineral source)
*Uranium (chief source of fissionable material)
Uranium-bearing minerals ~~(see special list.~~
Water (for cooling)
*Zinc (for cooling pipes)
Zirconium